Thermal Performance Characterization of Lightweight Concrete Incorporated with Polystyrene

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Received 1 April 2014; Accepted 9 June 2014; Published 8 July 2014

Abstract

This paper presents a study of the thermal properties of polystyrene lightweight concretes used as thermal insulation in buildings. Concrete mixtures, prepared using an identical matrix and differing dosage of polystyrene by replacing a portion of the volume of cement paste with polystyrene beads.

Keywords

Buildings; Thermal Properties; Thermal Conductivity; Thermal Resistance; Lightweight Concrete; Polystyrene

Introduction

Optimizing energy consumption is one of the building designers concerns. This explains the technology assessment and development of new building materials. Among these materials lightweight concrete, which can be play a role as an insulator, while maintaining adequate levels of performance. The knowledge of the materials thermal properties used for building shielding such as thermal conductivity and thermal resistance are the most important features for the choice of a thermal insulation material. This work is a contribution to the experimental study of thermal behaviour of polystyrene lightweighted concrete, his lightness make it an interesting technical solution for the building tower [Miled K, 2005]. The thermal conductivity of this material is measured in the conditions similar to those of utilisation by "method of Boxes", thermal resistance is obtained by calculation.

Studied Materials

We have chosen to make mixtures with an identical matrix and a different dosage of polystyrene, by replacing a portion of the volume of cement paste with polystyrene beads. Then we stopped as the volume occupied by the polystyrene became so important that it became difficult for the mixer to mix everything. The amount of polystyrene beads inserted is a mass fraction of the mass of cement. The dosages of fibre (P/B) were studied are: 0, 1, and 3 %. The used matrix consists of Portland cement (CPJ45, CMII), sand (0/4), and water. Table (1) lists the various mixtures studied.

TABLE 1 STUDIED COMPOSITIONS

Cement (Kg)	450		
Sand (0/4) (Kg)	1350		
Water (l)	225		
E/C	0.5		
Polystyrene mass (Kg)	0	4.5	13.5
Designation	B	BP1	BP3

Thermal Conductivity Measurements

Many methods are used for measuring the materials thermal conductivity, among them we chose the "boxes method", which was developed in the laboratory of Thermal and Solar Studies of the Claude Bernard University in France. It's of substantial precision, because the relative error on the measurement is evaluated to 5%. This method made the object of several publications [Azizi S., 1989]. It uses parallelepiped samples from sizes are (27cm× 27cm) and thickness varies from 2 to 7cm. The thermal conductivity measurements are based upon steady heat conduction. The sample is set between two atmospheres (Fig.1). Their temperature corresponds to real cases. As surroundings are at the same

temperature as upper boxes, the power supplied by the electrical resistance goes through the sample and the thermal conductivity is given by [Bulletin technique]:

$$\lambda = \frac{e}{S\,\Delta T}\left[\frac{V^2}{R} - c(T_b - T_a)\right] \quad (1)$$

With:

λ: thermal conductivity (w / m K)
e: thickness of the sample (m)
S: surface of the sample (m²)
T_c: hot surface temperature (°C)
T_f: cold surface temperature (°C)
V: applied tension (Volts)
R: electrical resistance (Ω)
c: coefficient of thermal loss through the box (W / K)
T_b: interior ambiance temperature (°C)
T_a: room temperature (°C)

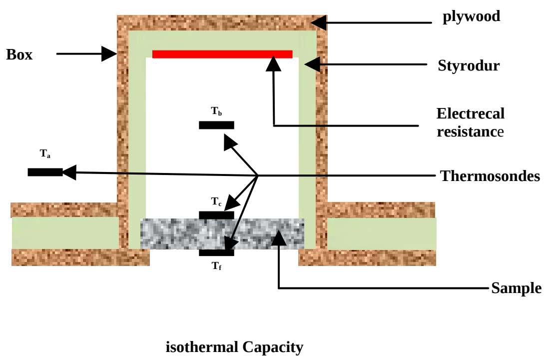

FIG. 1 BOX MEASUREMENT OF THERMAL CONDUCTIVITY

The value of thermal resistance R_{th} (m^2 .K /W) is expressed as:

$$R_{th} = \frac{e}{\lambda} \quad (2)$$

Results and Discussion

Measurements of apparent thermal conductivity of the materials studied are performed in the dry state, the saturated state, and different degrees of moisture. The levels of successive moisture contents were obtained by first saturating the samples tested, then the desaturated by drying in a ventilated oven, this technique allows to obtain a distribution as uniform as possible from the water within samples [Horton R. et al., 1982].

Effect of Moisture

The results of measuring the thermal conductivity in terms of water content obtained are summarized in Table 2 and Fig. 2:

TABLE 2 THE THERMAL CONDUCTIVITY OF THE STUDIED SAMPLES IN DRY AND SATURATED STATE.

Designation		B	BP1	BP3
λ (W m⁻¹ .K⁻¹)	Dry state	0.689	0.410	0.146
	Saturated state	0.850	0.558	0.324

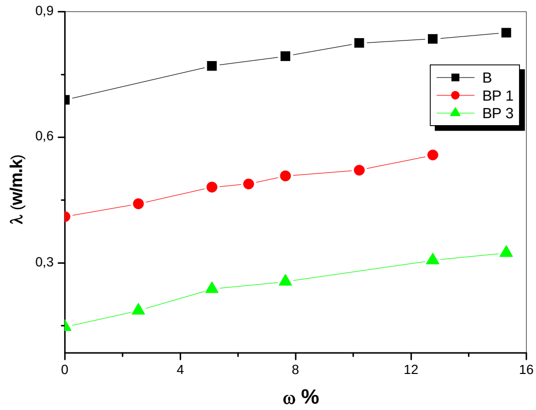

FIG.2 THERMAL CONDUCTIVITY IN TERMS OF WATER CONTENT OF POLYSTYRENE LIGHTWEIGHTED CONCRETE

For all materials studied, we can observe that the variation of thermal conductivity is not linear, it growth rapidly between (0 and 8%) for B, between (0 and 6%) for BP1, and between (0 and 4%) for BP3. This is explained by the fact that the materials which we studied are porous, in the dry state, the thermal conductivity depends only on that of the solid matrix and that of air which is partially replaced by the water in the pores during the wetting, and the value of thermal conductivity will depend on that of water. Thus a higher concentration of water increases the thermal conductivity.

TABLE 3 THE THERMAL RISISTANCE OF THE STUDIED SAMPLES IN DRY AND SATURATED STATE.

Designation		B	BP1	BP3
$R_{th} \times 10^3$ (m .K .W⁻¹)	Dry state	58	98	273
	Saturated state	47	72	124

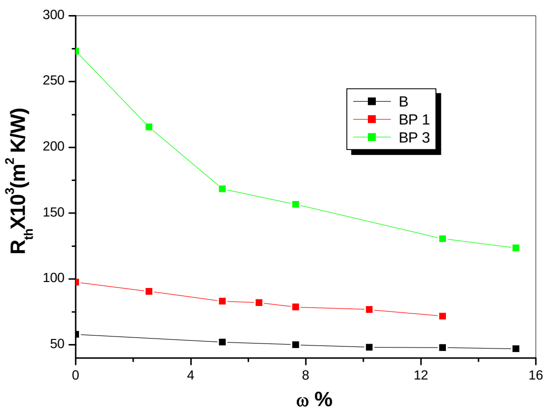

FIG.3 THERMAL RESISTANCE IN TERMS OF WATER CONTENT OF POLYSTYRENE LIGHTWEIGHT CONCRETE

The Table 3 and Fig. 3 show that the thermal resistance decreases with increasing of water content. If we take a wall of about 4cm thickness (BP1), the thermal resistance decreases from 98×10^{-3} $m^2.K/W$ at the dry state to 72 $\times10^{-3}$ $m^2.K/W$ at the saturated state, this leads to say that the more the wall is wet, the more it is heat-resistant.

Effect of Polystyrene Dosage

The evolutions of the thermal conductivity and thermal resistance of lightweight concrete in terms of polystyrene dosage have been presented in Fig. 4:

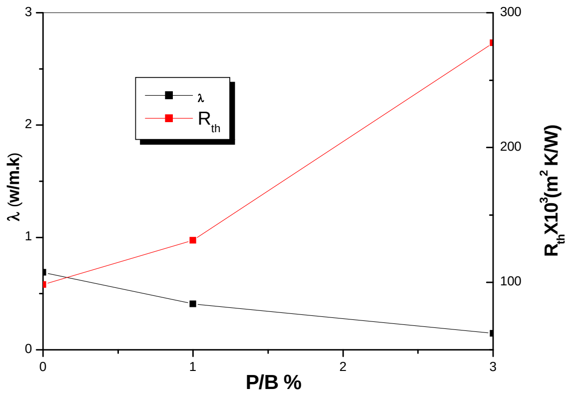

FIG.4 VARIATION OF THE THERMAL CONDUCTIVITY AND THERMAL RESISTANCE IN TERMS OF POLYSTYRENE AGGREGATES DOSAGE P/B

We observe a sharp increase of the thermal resistance with increasing the dosage, though the conductivity decreases slightly, we can see that the growth of the conductivity and the decrease of thermal resistance are equal, this is explained by the fact that the thermal conductivity of the polystyrene is very small compared to that of cement. So, the increasing of the polystyrene beads dosage in concrete, it makes it more thermally insulated.

Conclusions

From this study and from the simultaneous measurement of thermal characteristics of the polystyrene lightweighted concrete, we conclude:

- The influence of moisture on thermal insulation materials is negative, the presence of liquid characterized by a thermal conductivity thirty times higher than that the air will definitely cause an increase in thermal conductivity and decrease in thermal resistance of materials and insulation will decrease. These result confirmed those found by [Meukam P., et al., 2003; Boukhattem L., et al., 2007; Chereches M., 2008].

- The thermal proprieties of the materials investigated are strongly influenced by the density, the thermal conductivity increases and the thermal resistance decreases gradually as the material is dense.

- The addition of polystyrene beads in the initial material improves thermal performance.

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